Case Study: Results from the First U.S. Field Trial of Oxidation Technology for Coal Mine Ventilation Air Methane

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2008 U.S. Coal Mine Methane Conference
October 28-30, 2008

CONSOL Energy Inc.

- Largest producer of high-Btu bituminous coal in the U.S.
  - 17 mining complexes in six states
  - Proven and probable coal reserves of 4.5 billion tons
- Leads nation in production of coal from underground mines
- Produced 64.6 million tons of coal in 2007
- Majority shareholder in one of the largest U.S. producers of coal bed methane
  - CNX Gas Corporation
- Emitted 28.4 million cubic feet of coal mine methane in 2004
  - 88.7% ventilation air methane

CONSOL ENERGY
America's On Switch.

MEGTEC Systems, Inc.

- $260 million international company
- One business unit supplies air pollution control systems for destruction of volatile organic compounds
- One of the largest manufacturers of oxidation systems in world
- Evaluating and testing technologies for conversion of coal mine methane into energy for over 10 years

Methane Emissions from Coal Mines

- Methane is 2nd most important non-water greenhouse gas
- Coal mine methane (CMM) accounts for 10% of anthropogenic methane emissions in the U.S.
- Ventilation air methane (VAM) is single largest source of CMM
  - VAM was 76 billion cubic feet of the 142 billion cubic feet of CMM emitted in the U.S. in 2005
- Use of mine ventilation air is problematic due to low methane concentration, 0.3% to 1.5%

Coal Mine Ventilation Fan

Methane Conversion through Oxidation

- Oxidation process converts methane to CO_2 and water
  - Reduce greenhouse gas emissions
  - Reduces warming potential by 87%
- Potential to integrate a heat recovery system
  - Recover useful energy in the form of hot water, steam, or electricity
  - Avoids GHG emissions associated with the avoided fuel
- Produces essentially no SO_x, NO_x, or CO

Application of Oxidizer Technology

- Oxidizer technology has widespread industrial use for destruction of volatile organic compounds
- Thermal flow reversal reactor (TFRR) system is self sustaining at low methane concentrations (0.2%-1.2%)
  - MEGTEC VOCSIDIZER
- Two slipstream tests conducted at coal mines in Great Britain and Australia
- Full-scale TFRR system producing electricity on an active Australian coal mine

First U.S. Field Trial

- Demonstrate MEGTEC's commercial size TFRR reactor on an inactive coal mine
  - Windsor Mine, West Liberty, WV
- Simulate mine ventilation air by blending methane emissions from a mine vent with air

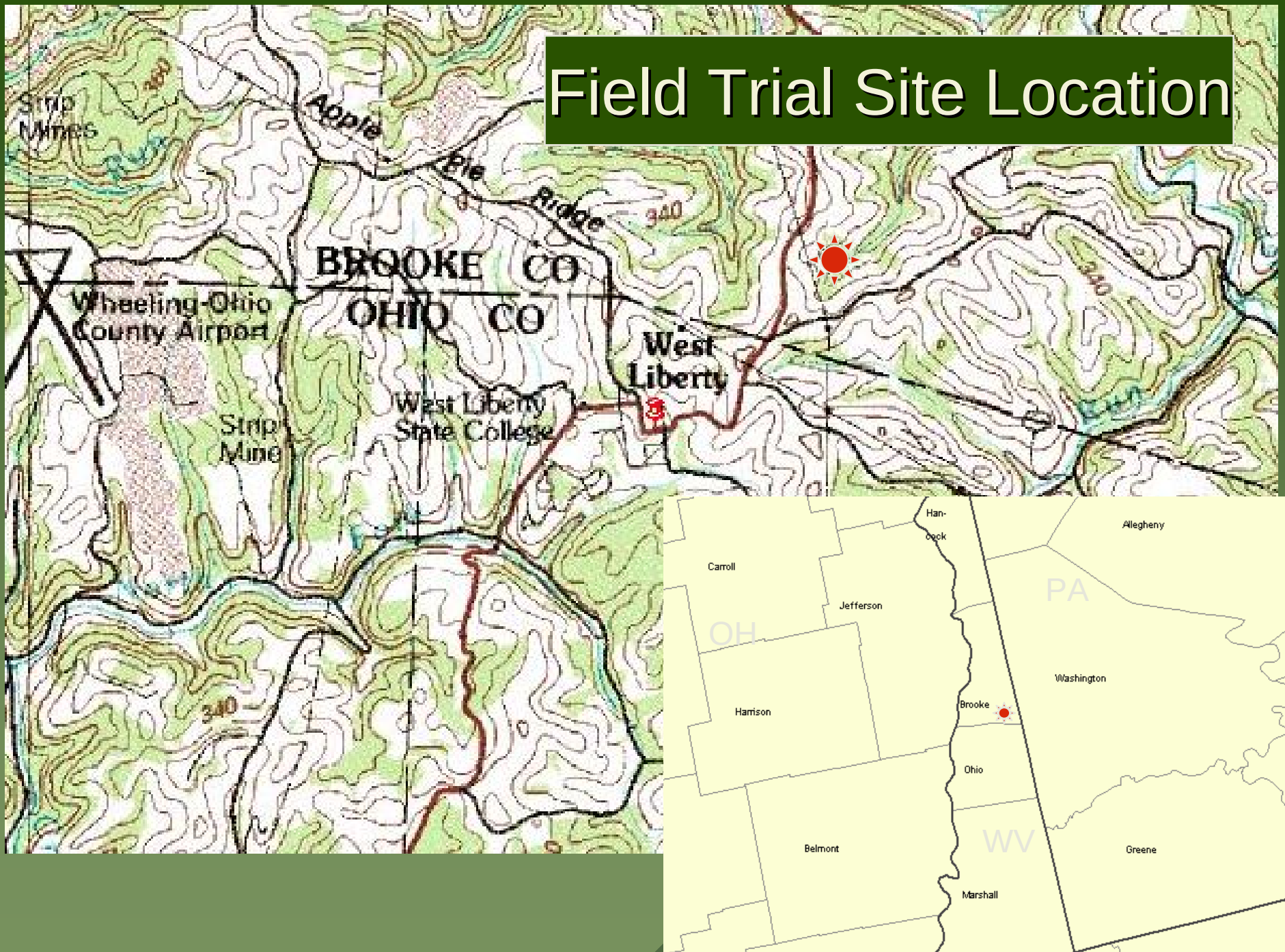
Opportunities of Trial

- Test the equipment without impacting the operation of an active mine
- Gain hands-on experience with the technology
- Verify safety systems
- Collect operability and maintenance data on the equipment
- Allow observation by MSHA and other government agencies
- First step for future installation on a mine ventilation fan

Project Objectives

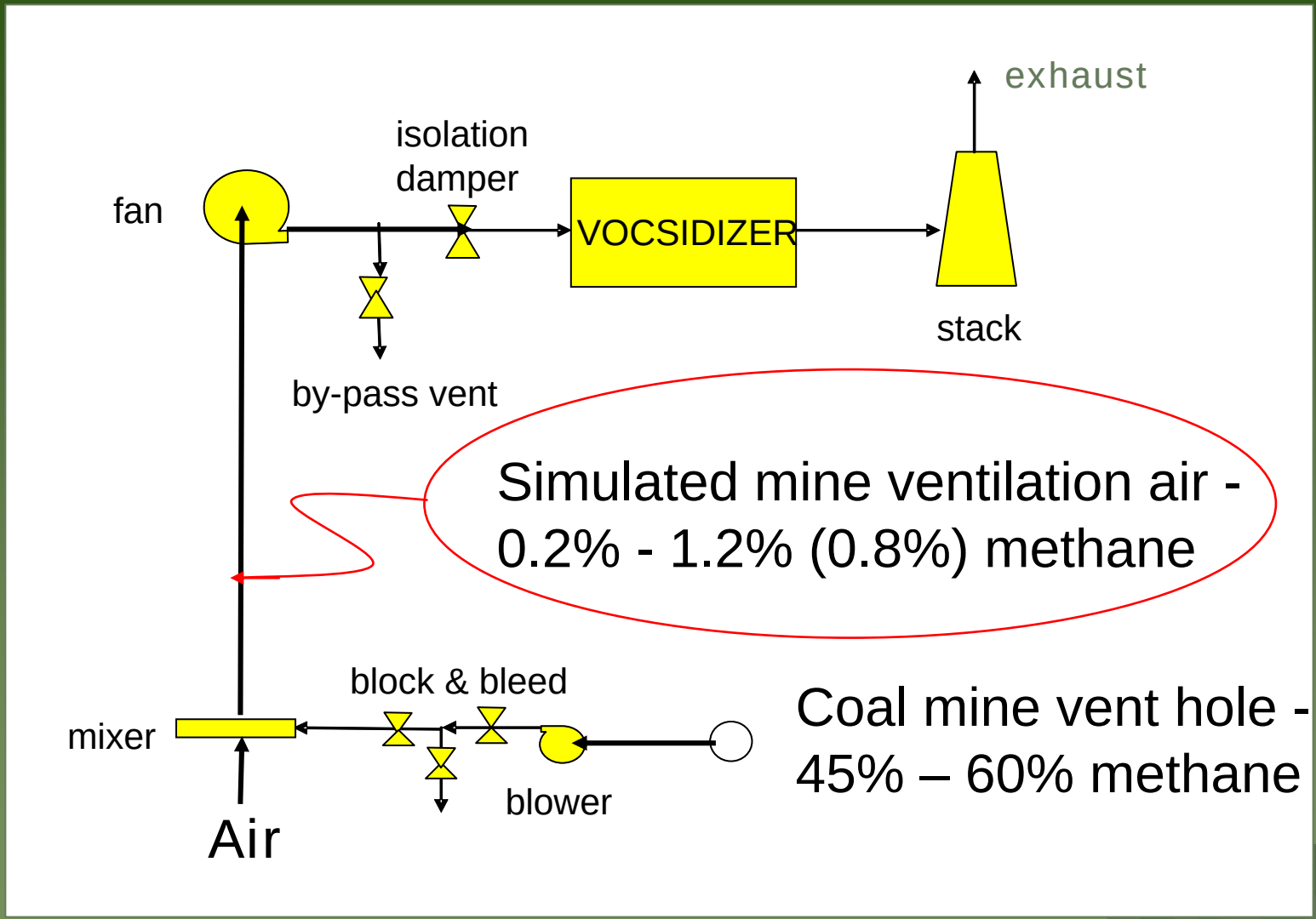
- Determine the long-term technical/economic feasibility of applying a full-scale thermal flow reversal reactor (TFRR) system to the safe and efficient operation of a large underground coal mine
  - Convert the low and variable concentration of methane in the simulated mine ventilation air to carbon dioxide effectively
  - Determine cost of applying technology
  - Determine the quantity of useful energy that can be economically produced

Field Trial Site Location



Windsor Mine Site

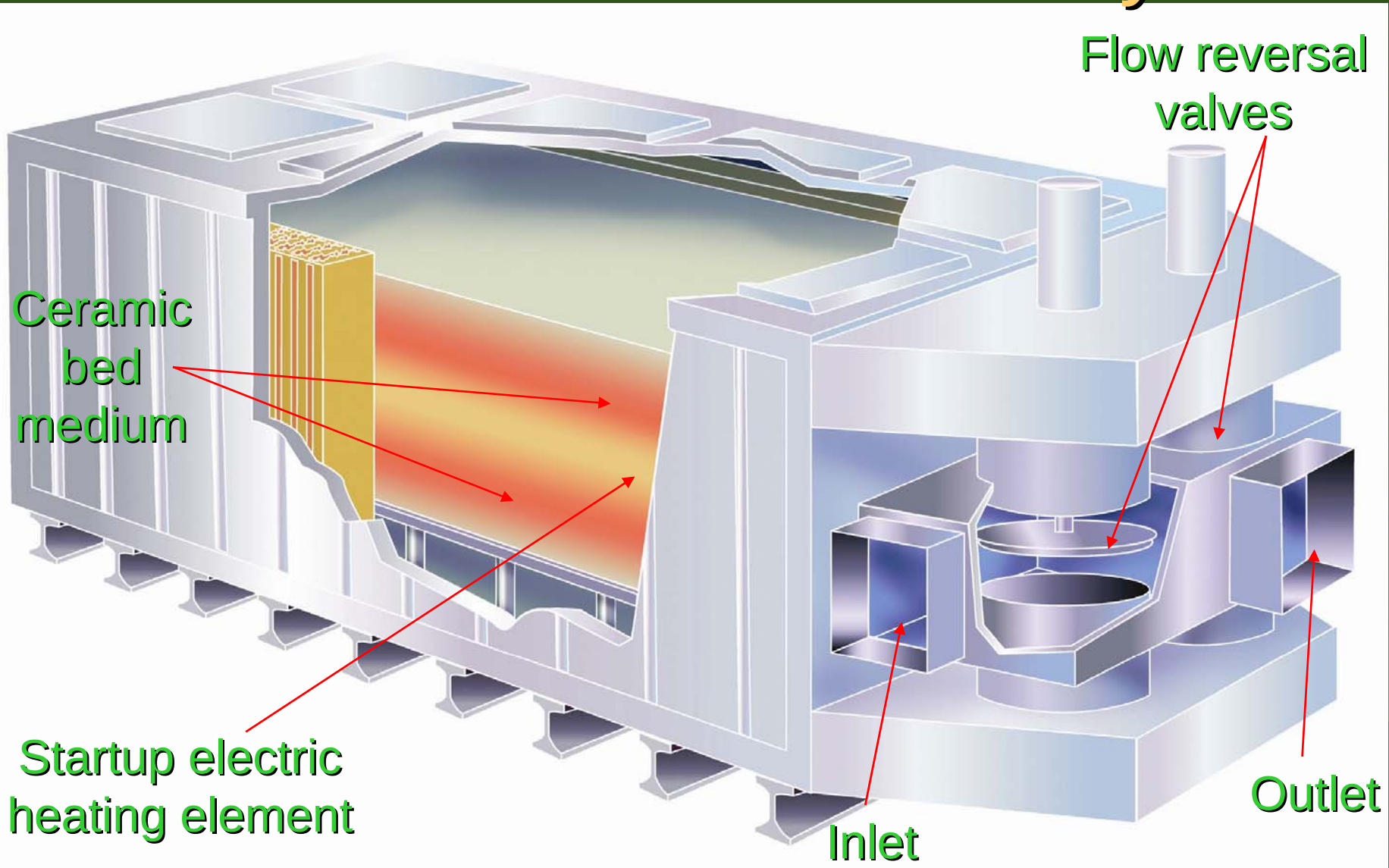
Field Trial Schematic Diagram



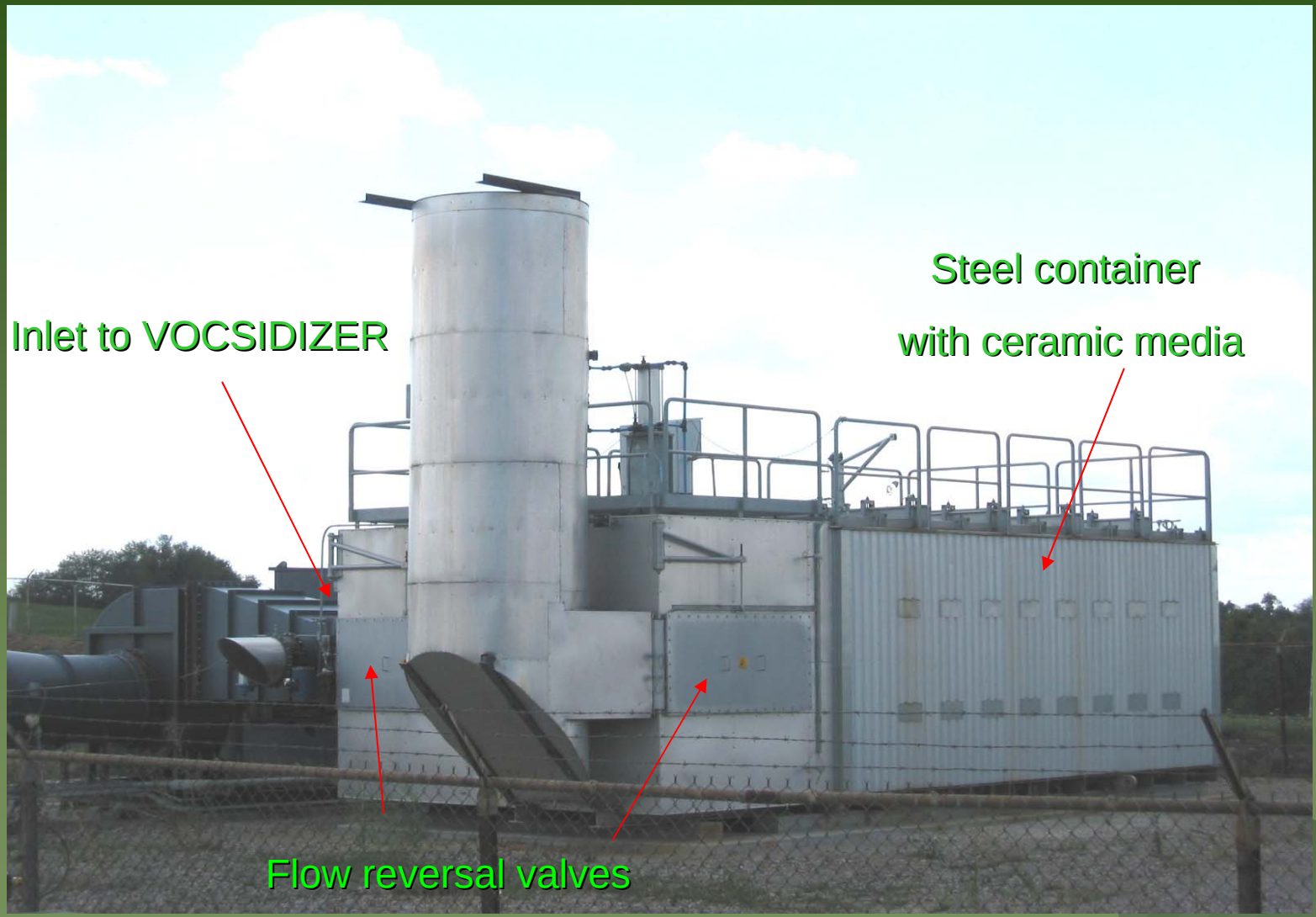
VOCSIDIZER Technology

- Single bed modular system to process 30,000 scfm of mine ventilation air
- Large bed of ceramic material in an airtight steel container
- Air plenum chambers above and below the bed
- Startup electrical heating element in the center of the bed
- Pneumatically actuated valves to control flow

VOCSIDIZER Cut-Away



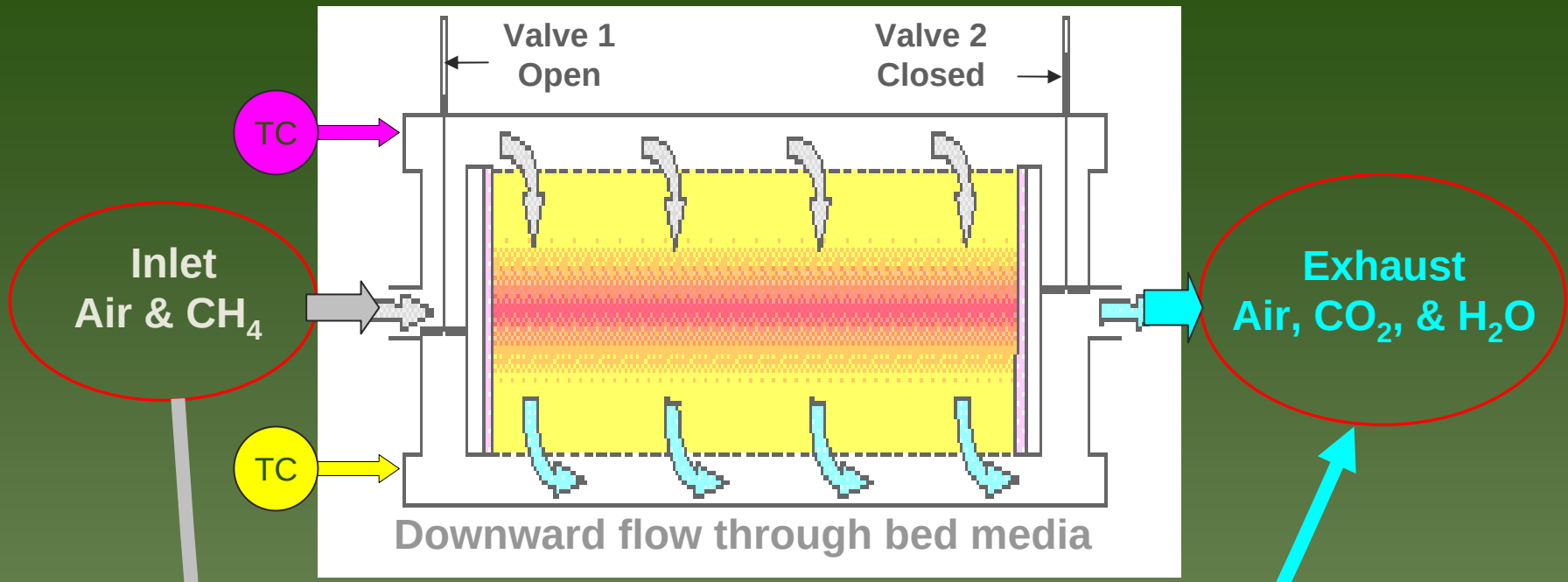
VOCSIDIZER at Windsor Mine

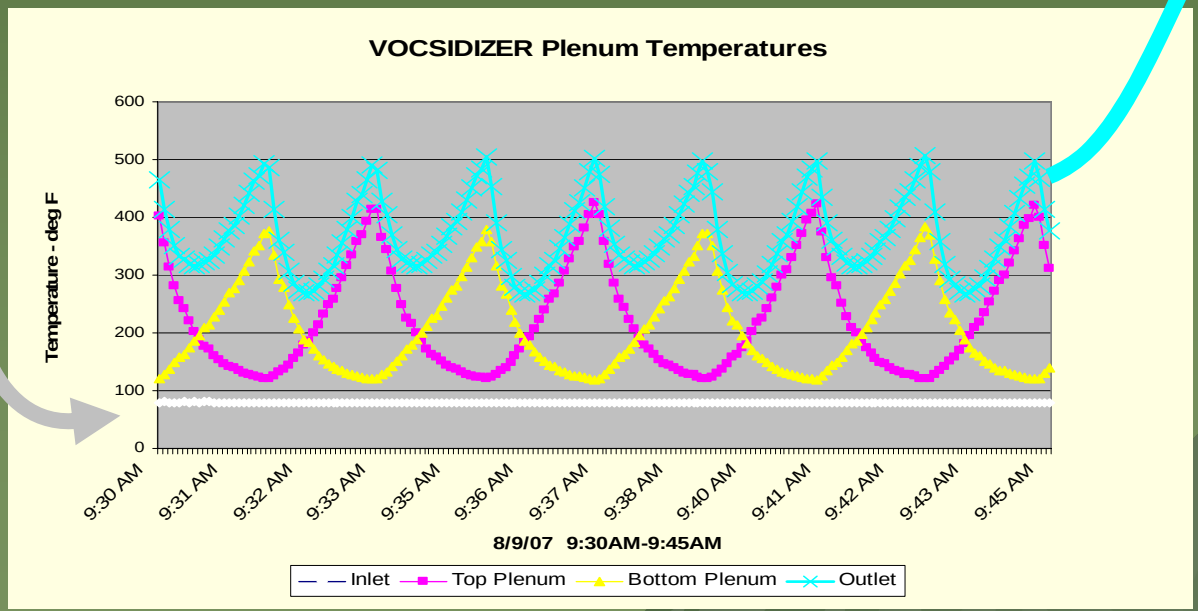


Principle of Operation

- Electric heating element brings the temperature to 1000 °C (1832 °F) at startup
- Process fan forces the air into the plenum and through the bed
- Air is heated to temperature at which methane is completely oxidized
- Thermal energy released by oxidation is recovered by the bed medium
- Air flow is reversed, and the heat recovered in the first cycle heats the incoming ventilation air to oxidation temperature
- Process repeats

Air Flow in TFRR

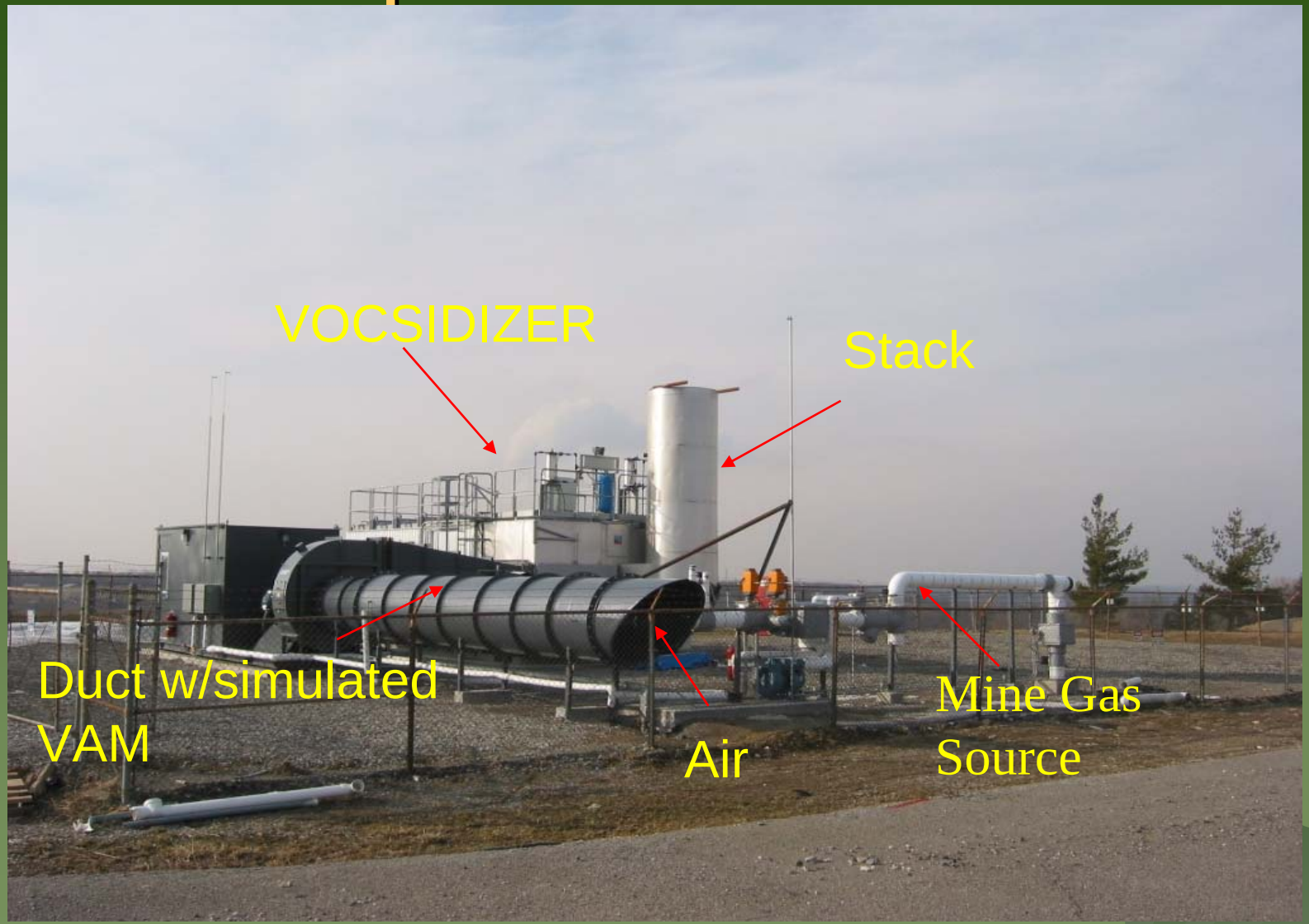




Principle of Operation

- Reaction zone stays in the center of bed where oxidization temperature is sustained
- Oxidation reaction takes place without auxiliary fuel and without a flame
- Methane conversion of 95%

Completed Installation



Operation

- Parametric testing
  - Determine effects of mine ventilation air flow rate and methane concentration on bed temperature and methane conversion
- Emission testing
  - Periodic stack testing to determine emissions
- Long-term testing
  - Evaluate operability over time
    - Phase I
    - Phase II

Parametric Tests

- Test five or six sets of operating conditions
- Three thirty-minute sample periods during steady-state operation
- Gas samples collected of VOCSIDIZER inlet and stack
- Analyze for methane concentration
- Calculate methane conversion
- Two separate test campaigns

Parametric Test Plan - Campaign 2

Test Run ID	Methane Concentration (%)	Process Air Flow Rate (scfm)
Test A	0.3	15,000
Test B	0.8	15,000
Test C	0.3	30,000
Test D	0.8	30,000
Test F	0.6	22,500

Bed Performance Results Campaign 2

	Test A	Test C	Test D
Target % CH_4	0.3	0.3	0.8
Actual % CH_4	0.29	0.30	0.79
Target flow, scfm	15,000	30,000	30,000
Actual flow, scfm	16,738	29,812	29,824
Temperature stack, ˚F	196	192	453
Delta T bed, ˚F	133	133	364
Maximum bed temp, ˚F	1897	1945	2095
% CH_4 Conversion	97.9	98.8	97.8

Emission Tests

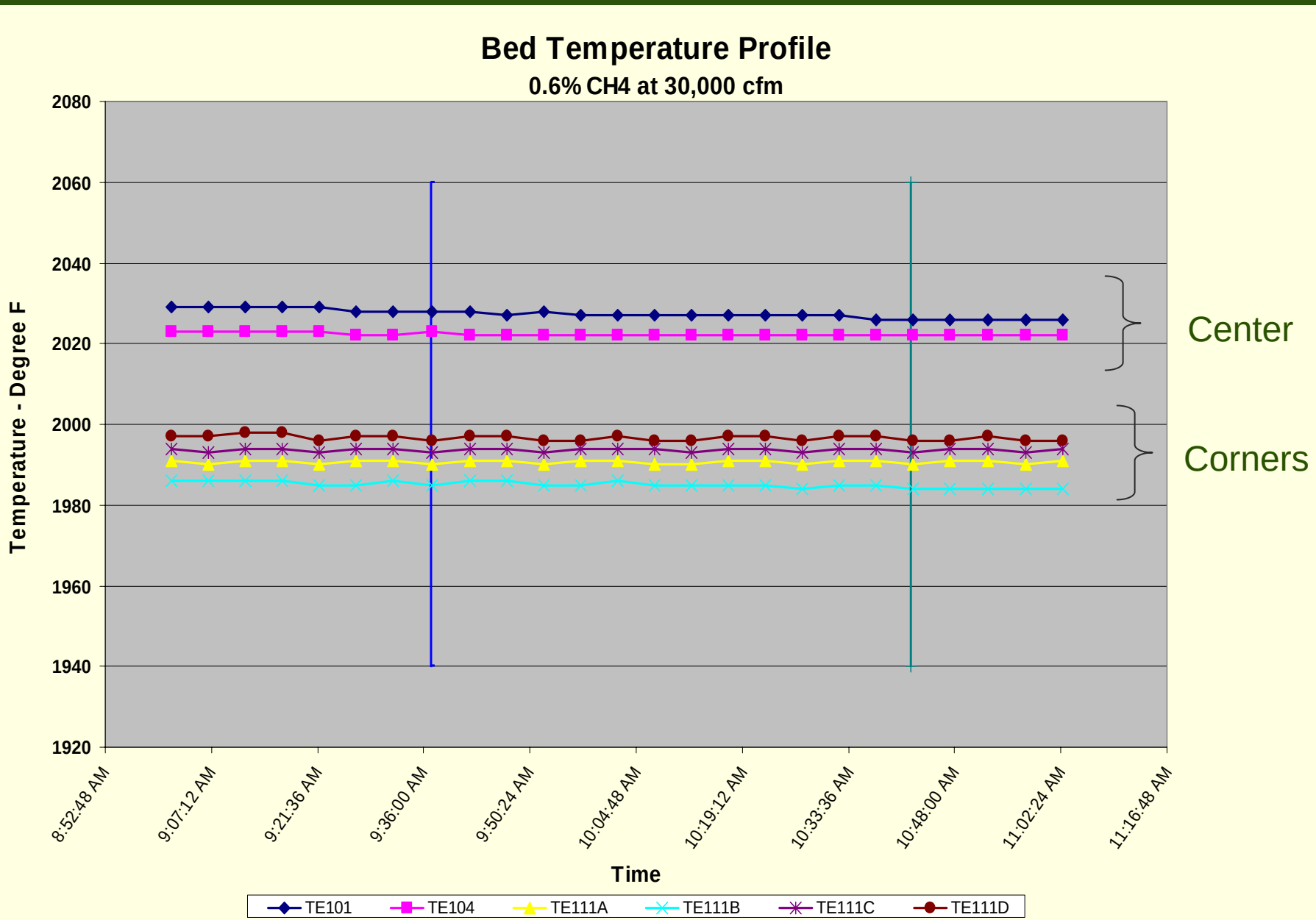
- Three test campaigns conducted
  - August 7-9, 2007
  - August 5-7, 2008
  - September 8-10, 2008
- Three one-hour tests per campaign
- Steady state conditions
  - 30,000 scfm process air
  - 0.6% methane concentration
- Measure SO_x, NO_x, CO, CO_2, O_2, VOCs, and particulate matter

Emission Test Results Campaign 2

	VOCSIDIZER inlet gas composition	stack gas composition	CH_4 conversion
CH_4	0.47 %*	165 ppmv	96.6 %
C_2H_6	< 0.01 %	< 0.01%	
CO_2	0.11 %	0.65%	
O_2	20.6 %	19.7 %	
N_2	77.2 %	-	
CO		2.3 ppmv	
SO_2		0.05 ppmv	
NO_x		0.20 ppmv	

•Inlet methane value by GC analysis; LEL monitor reads 0.6%.

** PM emissions were 0.006 grains/DSCF or 2 lb/hr.


Bed Temperature Profile
0.6% CH4 at 30,000 cfm
Temperature - Degree F
2080
2060
2040
2020
2000
1980
1960
1940
1920
8:52:48 AM
9:07:12 AM
9:21:36 AM
9:36:00 AM
9:50:24 AM
10:04:48 AM
10:19:12 AM
10:33:36 AM
10:48:00 AM
11:02:24 AM
11:16:48 AM
Time
TE101
TE104
TE111A
TE111B
TE111C
TE111D
Center
Corners

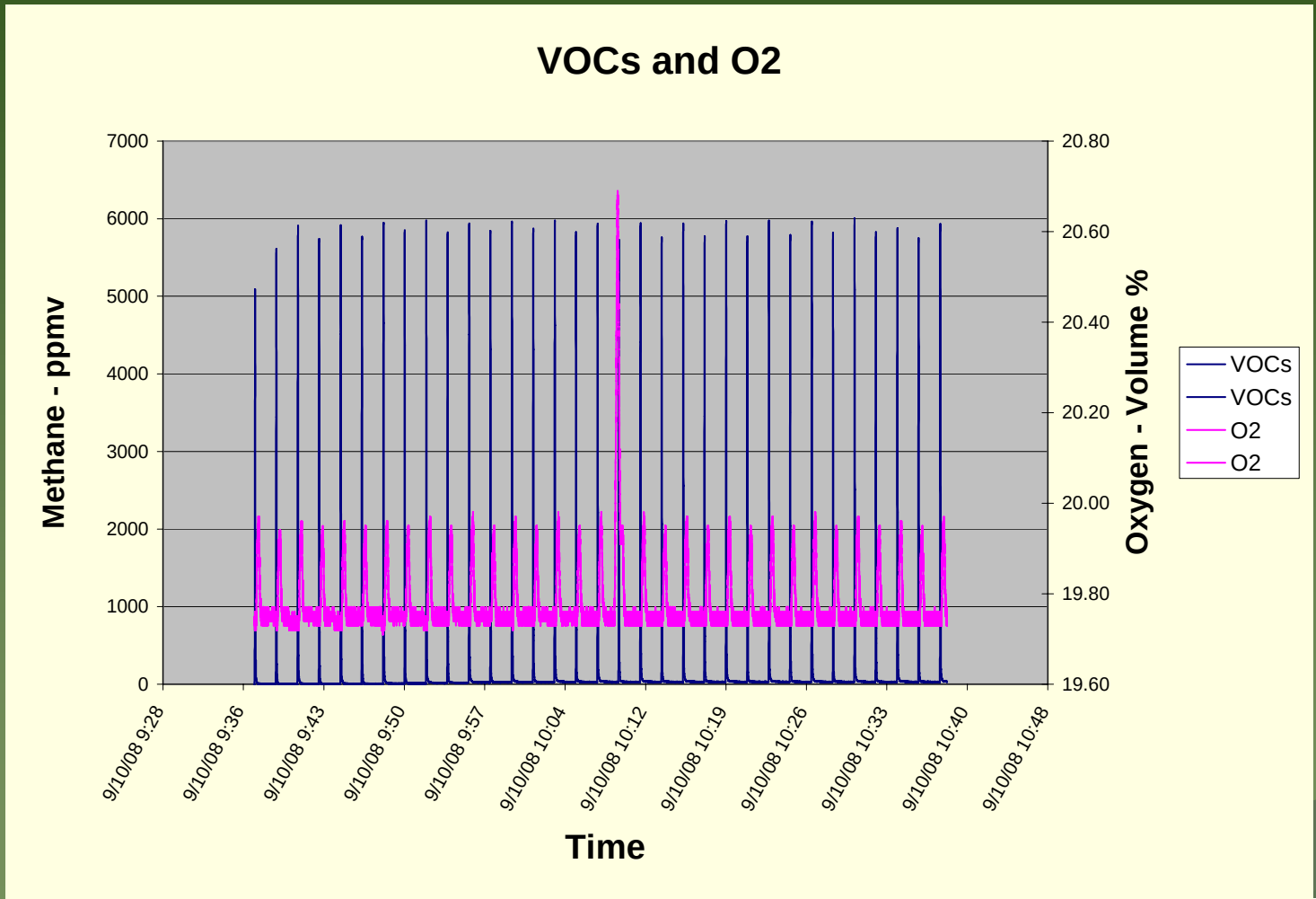
Emission Test Results Campaign 3

	VOCSIDIZER inlet gas composition	stack gas composition	CH_4 conversion
CH_4	0.42 %*	154 ppmv	96.4 %
C_2H_6	< 0.01 %	< 0.01%	
CO_2	0.09 %	0.64%	
O_2	20.7 %	19.7 %	
N_2	77.6 %	-	
CO		5.7 ppmv	
SO_2		0.05 ppmv	
NO_x		0.22 ppmv	

•Inlet methane value by GC analysis; LEL monitor reads 0.6%.

** PM emission data not available

Continuous Emission Monitoring Campaign 3 - Test 2



Long-Term Testing

- Objective to operate for 8 months continuously unmanned
- Operate at conditions typical of mine ventilation fan
  - 30,000 scfm process air
  - 0.6% methane concentration
- Collect operating and maintenance data

Operating Time-Phase I

- Simulated ventilation air methane introduced to VOCSIDIZER on February 11, 2007
- Total of 1300 unmanned operating hours from May 9, 2007 through November 30, 2007
  - ~27% availability
- More maintenance than expected
- Unreliable utility power responsible for some shutdowns

Operating Problems

- Methane detectors
  - Response time and accuracy did not meet requirements
- Air compressor system problems
  - Mechanical failure of components
  - Inability to maintain discharge pressure
- Temperature sensing problems
  - Failed thermocouples
- Bed media problems
  - Caused temperature control/profile problems
- Remote location
  - Caused longer than necessary times for restart

Operating Time - Phase II

- Re-commissioned the equipment in April 2008
- Maximum inlet methane concentration reduced to 0.8% from 1.2%
- Long-term tested resumed May 1, 2008
- Total of 2180 unmanned operating hours through September 30, 2008
  - ~59% availability
  - ~84% availability if excluding all “non-core” problems

Interim Operating Results

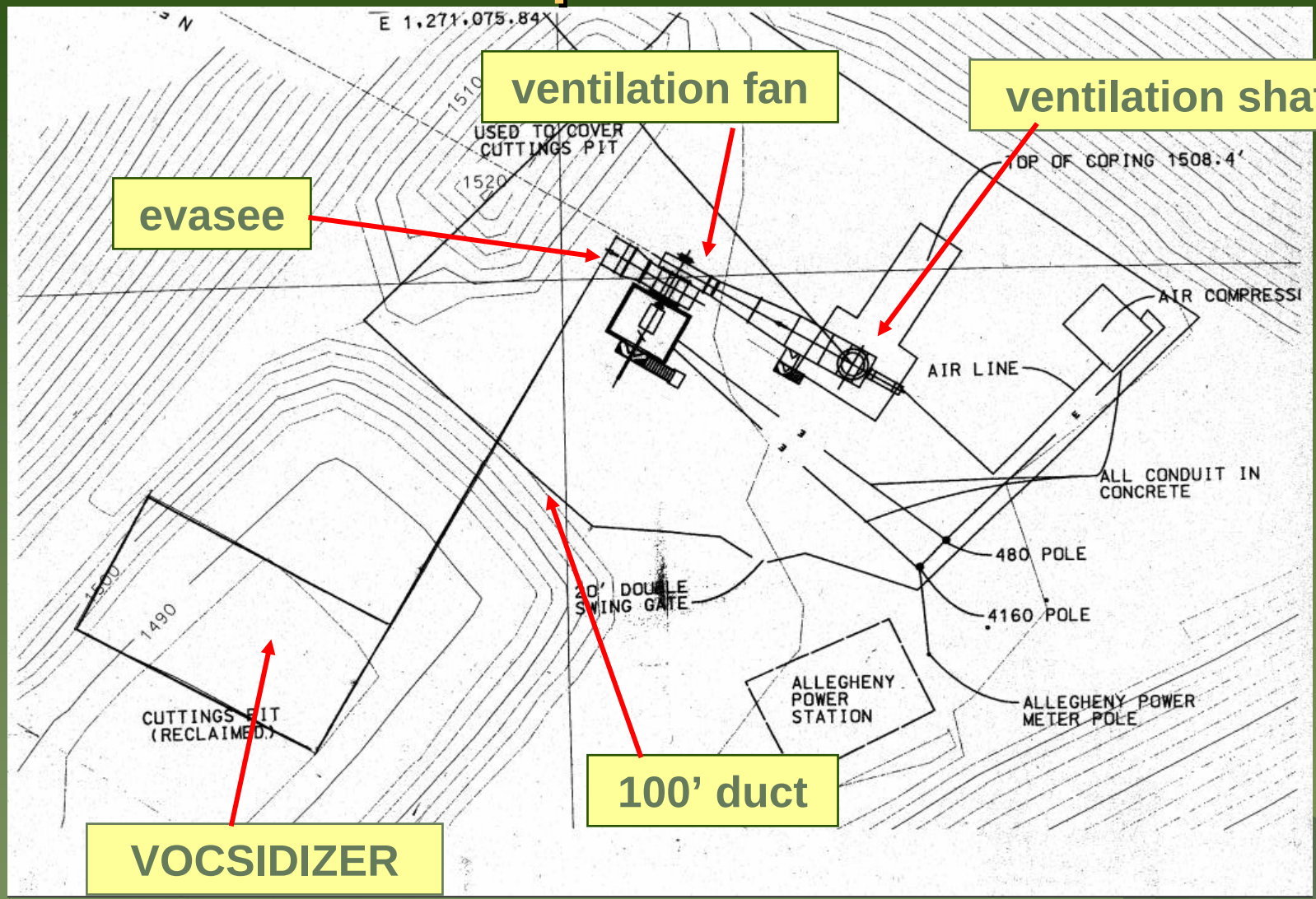
- Methane conversion meets spec (≥ 95%) at all conditions tested
- Pollutant emissions meet spec
- Self-sustained operation demonstrated at methane concentrations ranging from 0.3% at half flow to 1.0% at full flow
- Modified design limits methane concentration to ≤ 0.8%
- Equipment modifications greatly improved availability, but on-going long-term testing reveals some remaining maintenance concerns
- Some additional improvement modifications are expected

Plans and Schedule

- Continue long-term testing through October 2008
- Complete engineering/economic evaluation of a conceptual large commercial-size installation (180,000 cfm) with energy recovery system
- Final report to be submitted end of 2008
- Relocate equipment to mine ventilation fan on an active mine in 2009

Typical Ventilation Fan Site

Example Site Plan



Commercial VOCSIDIZER - Australia

Potential for Applications

- 180,000 cfm unit reduces methane emissions by 0.5 to 1.1 bcf/y
- Global warming potential reduced by 188,000 to 377,000 metric tonne per year CO_2e
- Thermal power of 18 - 36 MW
- Electricity generation of 5.4 – 10.8 MW possible
- Reduce demand on fossil fuel generating stations and resulting emissions of criteria pollutants and CO_2

Assumes methane concentration range of 0.6% - 1.2%; 100% availability; 95% methane destruction; GWP of methane = 21X CO2; GWP reduction of 87% upon oxidation; generating efficiency of 30%.

Acknowledgements

- U.S. Department of Energy, National Energy Technology Laboratory
- U.S. Environmental Protection Agency, CMOP
- MEGTEC Systems, Inc.
- CONSOL Energy Inc.